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PRELIMINARY PIPELINE TESTING OF THERMALLY DEWATERED SASKATCHEWAN LIGNITE SLURRIES

Final Report

by

R. Gillies, M. Small and J. Lychak

SRC Pipeline Technology

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PRELIMINARY PIPELINE TESTING OF THERMALLY DEWATERED SASKATCHEWAN LIGNITE SLURRIES (UP-S-7-037) PART OF THE PROGRAM OF THE FEDERAL PANEL ON ENERGY R&D (PERD)

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MICROMEDIA

SUMMARY

A testing program has been completed to evaluate the potential of a thermal dewatering process for improving the pipelining characteristics of Saskatchewan lignite slurries. Lignite samples from the Estevan area were treated using the University of North Dakota's Energy and Minerals Research Center (EMRC) thermal dewatering (hydrotreating) process. In the EMRC hydrotreating process, the lignite was exposed to a high temperature (330°C) and high pressure (15,000 kPa) environment in a 2.2 tonne per day continuous unit. The hydrotreated lignite samples were tested in a 50 mm diameter pipeloop at the Saskatchewan Research Council's Pipeline Technology Centre in Saskatoon.

For lignite in water slurries, pipeline concentrations are normally limited to about 40% (by mass based on dried coal) because of the high intrinsic moisture content of the coal particles. Approximately 1.5 tonnes of water would have to be pipelined for every tonne of dry coal. Because of this very high water requirement, raw lignite slurries are often considered to be uneconomical for long distance transportation.

The Saskatchewan Research Council's pipeloop test results showed that, after hydrotreating, the intrinsic moisture level of the lignite decreased substantially and the pipeline concentration could be increased to at least 53%. Hydrotreated lignite would require less than 0.9 tonnes of water per tonne of dry coal and most of the water required to slurry the lignite could be recovered during the hydrotreating process. This reduced water requirement would translate into significant cost reductions for pipeline transportation of lignite.

The hydrotreating process also improves the energy content of the delivered coal. Dewatering processes such as centrifuging would produce significantly drier products from hydrotreated lignite slurries than from raw lignite slurries. Laboratory test results showed that the centrifuge cake moisture content was reduced from 45% for raw lignite to 31% for hydrotreated lignite.

Hydrotreated lignite was used to prepare two types of coal/water mixtures, an unstabilized slurry containing no added chemicals and a coal/water fuel slurry which contained stabilizing chemicals. The unstabilized slurry did not show any significant degradation during prolonged recirculation in the pipeloop and appeared to be suitable for long distance pipeline transportation. However, for the stabilized slurry, the pumpability deteriorated rapidly during recirculation in the pipeloop. The stabilized slurry would be unsuitable for long distance pipeline transportation. However, it is quite possible that different stabilizing chemicals would produce a more durable slurry. Since the results from this preliminary technical study were positive, a preliminary economic evaluation is now required. The economic evaluation should be followed by a large scale thermal upgrading and pipeline testing program to fully evaluate the technology and to determine the slurry flow characteristics in full diameter pipelines.

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1. INTRODUCTION

A study for the Federal and Provincial Environment Ministers (Reference 1) indicated that, if Ontario used low-sulphur western Canadian coal instead of imported American coal, Canadians would benefit by:

1. Reducing the acid rain problem in Eastern Canada.
2. Creating employment equivalent to 200,000 person-years over the next fifteen years.

Saskatchewan has immense reserves of lignite (15 billion tonnes) that are readily accessible and have one-tenth the sulphur content of imported American coals. The lignite reserves provide the SaskPower with the lowest costing thermal generating station fuel in Canada.

The Saskatchewan lignite deposits are much nearer to Ontario than other low-sulphur Canadian coal deposits but lignite has barely penetrated the Ontario coal market. Unfortunately, low ranking coals, such as Saskatchewan lignite, have high internal moisture contents and, hence, low energy densities (energy to mass ratios). Coals with low energy densities cannot be transported long distances economically. Also, few power plants in Ontario can handle raw lignite without suffering unacceptable levels of derating. The energy density has to be improved before the lignite can be widely used outside Saskatchewan.

Conventional direct drying of coal using hot gases improves the energy density, but in the case of lignites, the dried coal becomes dusty and subject to spontaneous combustion. Also, if the dried lignite is slurried in water, the coal particles quickly regain most of their original internal moisture.

temperature under a pressure great enough to prevent vaporization of the water. Physical and chemical changes, which take place during the thermal dewatering operation, force internal water from the coal in an energy efficient, and apparently irreversible, manner. The basic process was first patented by Fleissner in 1927 (Reference 2).

Since 1927, many studies have been conducted throughout the world to improve the Fleissner process. Evans and Siemon (Reference 3) were able to develop an energy efficient method for dewatering Australian brown coals. By driving off most of the water as liquid, they succeeded in drying the coal using only about 20% of the energy of an evaporative drying process. The University of North Dakota's Energy and Mineral Research Centre (EMRC) is developing a procedure for preparing high density coal-water mixtures from low ranking coals (References 4 and 5). The EMRC facility features a 90 kg per hour continuous process for thermally dewatering (hydrotreating) low-rank coals. The EMRC group have produced free flowing lignite slurries which contain more than 60% solids on a bone-dry basis.

Saskatchewan lignite has also been the subject of thermal dewatering studies. A CANMET sponsored study conducted by Saskatchewan Power Corporation and the University of Regina Energy Research Unit (Reference 6) included bench scale testing of several lignite samples. The study showed that the thermal dewatering process could increase the calorific value of Saskatchewan lignites to the level of subbituminous coals. The study also showed that the thermal dewatering process had a beneficial side effect; it produced significant reductions in sodium, potassium and sulphur contents of the lignite.

The low calorific value of lignite and the high sodium content of some Saskatchewan lignites restrict their use in coal-fired power stations. A thermal dewatering process which increases the energy density of lignite, while removing undesirable inorganics could substantially increase the potential market for Saskatchewan lignite.

The positive results obtained in the SPC study and the success of the EMRC group at preparing coal-water fuels from lignites need to be examined in terms of the potential for pipeline transportation. At present, transportation costs account for as much as 50% of the total cost of western Canadian bituminous coals delivered to Ontario. A pipeline transportation system for moving upgraded lignite to Ontario could offer substantial cost reductions.

The Saskatchewan Research Council (SRC) and the University of Saskatchewan have been studying the transportation of materials such as coal in pipelines since 1960. In 1970, Transport Canada decided to capitalize on the facilities and the expertise assembled at Saskatoon and established the Slurry Pipeline Development Centre. Today, the facility has a pilot plant with pipeline test loops ranging from 50 to 500 mm in diameter. Personnel at the Centre have studied the flow characteristics of all types of coal slurries including conventional (Black Mesa type) slurries, coal/water fuels, coarse coal slurries, coal in oil mixtures and coal in methanol slurries.

A proposal to study the pipeline flow characteristics of thermally upgraded lignite slurries was submitted to Supply and Services Canada during 1987. It was proposed that a sample of Saskatchewan lignite be upgraded the EMRC hydrotreating process and that the upgraded lignite be tested in a

small diameter pipeloop at the SRC facility. The pipeloop study was designed to determine if:

1. Significant pipeline energy reduction might be achieved by thermally upgrading lignite.
2. The thermally upgrading process would prevent lignite from regaining moisture during prolonged exposure to water in a pipeline.
3. The EMRC stabilized lignite coal/water fuel would be remain stable during pipeline transport.

The proposed study was approved for funding during the 1988/89 fiscal year. This report contains the results of the study.

2. PIPELINE BEHAVIOUR OF SLURRIES

Liquids such as water and crude oils normally show Newtonian fluid behaviour in pipelines. Figure 1 compares Newtonian fluid behaviour with common types of slurry behaviour in a pipeline. The frictional headloss, i is plotted against the bulk velocity, V for a Newtonian liquid, a homogeneous (fine-particle) slurry and a heterogeneous (coarse-particle) slurry. A finely powdered coal slurry (coal/water fuel) is an example of a homogeneous slurry and a run of mine coal in water slurry is an example of a coarse-particle slurry.

For a Newtonian fluid, the headloss will be proportional to the velocity if the flow is laminar. As the velocity increases there is a transition to turbulent flow. This transition velocity depends on pipe diameter, fluid density and viscosity. Under turbulent flow conditions, the headloss increases more rapidly (approximately with the square of the velocity). The laminar flow headloss is not affected by the conditions of the pipe wall but the turbulent flow headloss is highly sensitive to the wall roughness.

If a slurry is non-settling or if the particles settle slowly, then the mixture may be considered to be fluid-like or homogeneous. Sometimes homogeneous slurries resemble Newtonian liquids but often they resemble non-Newtonian liquids with yield stresses (Bingham fluids) and/or shear rate dependence (power-law fluids).

Like a liquid, a homogeneous slurry will enter a turbulent flow regime as the velocity increases. The turbulent flow behaviour of single phase fluids is quite well understood and successful models have been developed for relating the turbulent flow behaviour of Newtonian and some non-Newtonian liquids and solutions to their laminar flow behaviour.

Unfortunately, the same is not true for mixtures. In turbulent flow, it is the nature of the mixture in the thin region closest to the pipe wall that ultimately determines the frictional headloss. Even slight concentration changes caused by particles migrating away from the pipe wall can have large effects on the headloss. Existing models for fine-particle slurry behaviour do not adequately deal with these radial concentration gradients which must exist during turbulent flow of fine-particle slurries. Mathematical models have been developed to show that fluids with yield stresses will have reduced turbulent flow friction factors. However, these models fail to explain the apparently low friction factors which often occur for turbulent flow of slurries which have no significant yield stresses.

Coarse-particle (or rapidly settling slurries) are classified as heterogeneous. As indicated in Figure 1, heterogeneous slurries often have high frictional headlosses. The large particles are not fully suspended by fluid forces and part of the immersed weight of the solids is transmitted to the wall of the pipeline. In addition to the normal fluid friction, there is another component due to particle-wall contact. For coarse-particle slurries, the laminar/turbulent transition is of less concern than the solids deposition velocity. There is a minimum velocity required to prevent a stationary bed of solids from forming along the bottom of the pipe. Also, if a slurry contains coarse particles, then there will be significant concentration gradients in the pipe even when the operating velocity exceeds the deposition velocity. There will also be velocity gradients since the dense mixture in the lower portion of the pipe will travel more slowly than the less concentrated mixture in the top part of the pipe.

Because of the complexity of slurries, viscometer results are often of limited use in attempting to predict pipeline behaviour. To completely define the pipeline flow characteristics of a slurry the following measurements would be required in pipeloops with diameters approaching those of commercial pipelines:

* The frictional pressure gradient.
* The minimum velocity required to prevent solids deposition.
* The density distribution of the flowing slurry.
* The velocity distribution of the flowing slurry.

This preliminary study was most concerned with determining whether the thermal upgrading process would produce gross improvements in pumpability of lignite slurries. For this reason, the tests were limited to measurement of frictional pressure gradients in a small diameter pipeloop. Large pipeloop tests and flow distribution measurements would form part of a future project assuming that the preliminary tests show positive results.

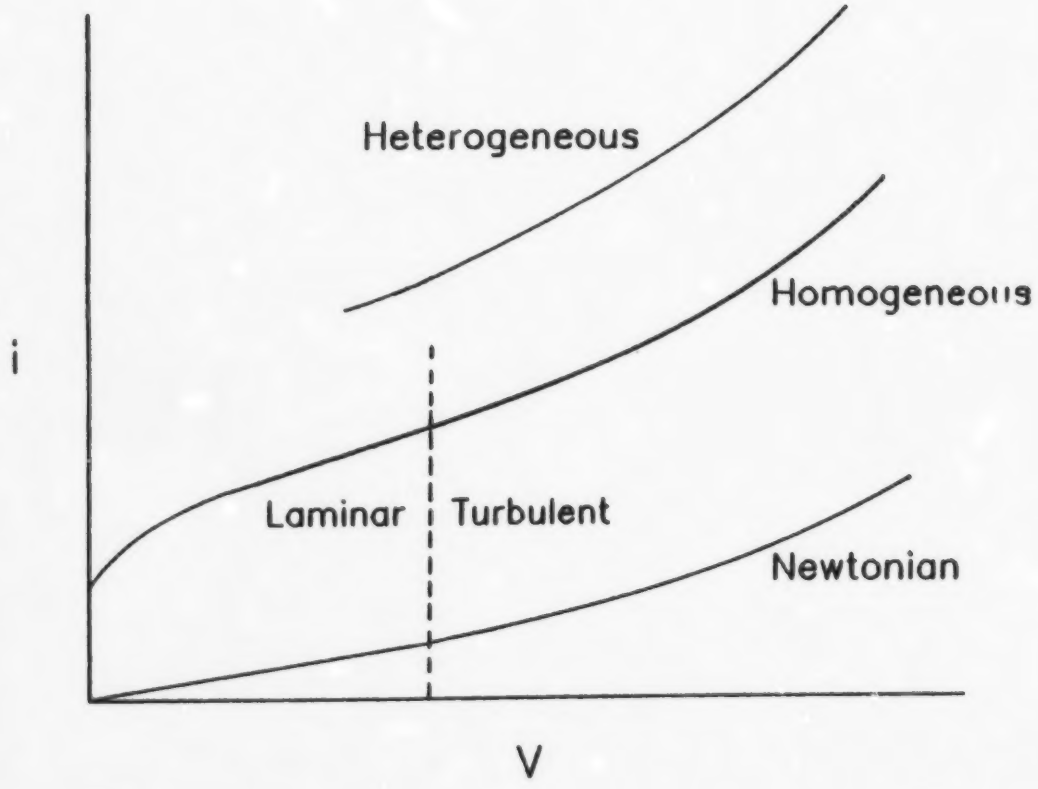


Figure 1: Typical Headloss-Velocity Relationships for Pipeline Flow of Slurries

3. EXPERIMENTAL

Coal Sample Preparation Procedures:

A sample of lignite was collected from the Boundary Dam power station near Estevan, Saskatchewan and delivered to EMRC during November 1988.

At the EMRC facility, the lignite was ground to two sizes, a conventional grind and a fine (coal/water fuel) grind. For the conventional grind, approximately 70% of the coal passed 150 mesh (0.105 mm). While this is considerably finer than a normal long distance pipeline grind, it is the maximum particle size that could be handled in the EMRC pilot plant equipment. The second portion was pulverized to 70% passing 325 mesh, a size distribution which is typical for coal/water fuel mixtures.

A portion of the conventional lignite sample was subjected to the EMRC hydrotreating process in their continuous Process Development Unit. (Details of the treatment procedure are given in Appendix B of this report). The fine lignite sample was also subjected to the hydrotreating process. The resulting fine coal/water fuel slurry was stabilized by adding 1.0% ammonium lignosulfonate and 0.2% xanthan gum.

The three coal samples (raw conventional lignite, hydrotreated conventional lignite slurry and fine hydrotreated/stabilized lignite slurry) were shipped to the Saskatchewan Research Council during December 1988. The particle size distributions, which were determined by sieving and by using sedimentation pipettes, are shown in Figure 2. The hydrotreated conventional lignite sample is considerably finer than the raw lignite sample. This shows that a considerable amount of particle degradation took place during the hydrotreating process.

Pipeloop tests were carried out on the three slurry samples during February and March 1989.

Pipeloop Testing Procedures:

The tests were carried out in the 50 mm diameter pipeloop shown in Figure 3. The pipeloop contains approximately 30 m of steel pipe and has an internal volume of 60 litres.

A 75 x 50 mm rubber-lined centrifugal pump is used to circulate the slurries and a variable-speed belt drive is used to provide flowrate control. A magnetic flux flowmeter is used to determine the slurry velocity.

A chilled glycol/water mixture is circulated through the annulus of a pipe-over-pipe heat exchanger to control the slurry temperature during the pipeloop tests.

A differential pressure transducer is used to measure the frictional headloss over a 5.49 m long horizontal test section. The test section is coated internally with an epoxy resin and has a diameter of 51.5 mm. The effective roughness of the test section is determined from frictional headloss measurements with water. The effective roughness was found to be 0.006 mm.

The magnetic flowmeter and differential pressure transducer were carefully calibrated prior to the series of tests. A computer was used to monitor and record the instrument readings.

The pipeloop contains a glass section of pipe which is used to inspect the slurry flow and to make visual determinations of the solids deposition velocity (the velocity at which a stationary bed of solids forms on the bottom of the pipeline).

Pipeloop tests were conducted to determine the deposition velocity and to measure the frictional headloss for the lignite slurries. The tests were carried out in the following manner:

1. The pipeloop was filled with water and the headloss was measured at several flowrates. The data were used to determine the pipe wall effective roughness.
2. The pipeloop was emptied, dried and then filled with coal slurry.
3. The frictional headloss was measured against time while the slurry was being circulated at a constant velocity and at a constant temperature. Samples were removed for PSD and cake moisture determinations.
4. The slurry headloss was measured at several flowrates starting at a high velocity and reducing the velocity in a step-wise manner. The solids deposition conditions were determined by visual inspection.
5. The solids concentration was adjusted by diluting with water or by adding more coal and step 4 was repeated.

A flow diverter was used to remove samples of the flowing slurry. Tyler sieves were used to determine the particle size distribution (PSD) of the coarse solids (material retained on a 0.074 mm sieve). Sedimentation pipettes were used to determine the PSD of the fine solids fractions.

A 12.7 cm diameter screen-bowl centrifuge was used to prepare pipelined lignite samples for intrinsic moisture determinations. The samples were centrifuged at 2200 g's for 5 minutes. Cake moistures were determined by drying for two hours at 104°C. The centrifuging procedure offers a better indication of the amount of water that is removable by practical separation techniques than does the standard method of determining equilibrium moisture at constant humidity.

Pycnometers were used to determine the densities of the lignite samples. Vacuum was applied to the samples prior to performing immersed weight versus volume determinations.

Pipeloop Test Results: (See Appendix A for tabulated test data)

The frictional headlosses for lignite slurries flowing in a 51.5 mm diameter pipeline are shown in Figures 4, 5, 7, 8 and 9. The headlosses are presented in units of metres of water per metre of pipe.

Figure 4 shows the frictional headlosses for the raw conventional lignite slurries. At a solids concentration of 39%, the flow is laminar and appears to be Newtonian for all except the highest velocity. Using the slope of the headloss-velocity data for the laminar flow conditions, an effective viscosity of 78 cp is obtained. At lower concentrations, the upward curvature of the headloss-velocity data indicates that the flow is turbulent. Assuming Newtonian fluid behaviour, it is possible to calculate effective viscosities from the turbulent flow data. The effective viscosities are 6 cp and 12 cp at 26.3% and 32.0% solids respectively.

Figure 5 shows the effects of prolonged recirculation in the pipeloop on the frictional headloss for the hydrotreated conventional lignite slurry. The slurry travelled 120 km and experienced 4000 pump passes during the 54 hour long test. There is very little change in the headloss during this period. This indicates that the internal water removed during the hydrotreating process did not re-enter the lignite particles during prolonged exposure in the pipeloop. The flow is turbulent and the effective viscosity is 15 cp at a solids concentration of 41.9% (mass). This is considerably lower than the viscosity of the raw lignite slurry (78 cp at 39.0% solids).

The lower intrinsic moisture and to the broader size distribution of the hydrotreated lignite both contribute to the reduced frictional headloss.

Figure 6 shows the particle size distribution against recirculation time for the hydrotreated conventional lignite. The amount of particle attrition was quite small when one considers that the slurry experienced 4000 pump passes during the test.

Figure 7 shows the frictional headlosses for hydrotreated conventional lignite slurries over a range of solids concentrations. At the highest concentrations (52.6% and 50.9%) the flow is laminar throughout the flowrate range. The 48.8 and 46.5% slurries show transitions to turbulent flow at high velocities. The flow is turbulent throughout the test for the 26.5% slurry. Even at the highest solids loading (52.6%), the effective viscosity is only about 130 cp which is well below the upper limit for long distance pipelining applications. The fact that such a high solids loading could be achieved shows that the hydrotreating process is effective for improving the pumpability of lignite slurries.

Figure 8 shows the behaviour of the fine hydrotreated/stabilized lignite slurry. The slurry developed a large yield stress during 10.5 hours of recirculation in the pipeloop. The reason for the yield stress is not known but it must related to the presence of the stabilizing chemical. Because of the large yield stress, the stabilized slurry would be unsuited to long distance transportation.

Figure 9 shows the effect of solids concentration on the headloss for the fine hydrotreated/stabilized lignite slurry. The data shown are for slurry which had been recirculated for 10.5 hours and then diluted by adding water. The yield stress is strongly dependent on solids concentration.

Considerably higher solids loadings could be achieved using the hydrotreated lignite which had not been stabilized by chemical addition.

Figure 10 shows the relative viscosities of the conventional lignite slurries. The relative viscosity is the ratio of the slurry's effective viscosity to the viscosity of water at the operating temperature of the pipeline. It is apparent that the hydrotreating process is effective at increasing the solids loading for lignite slurries. Simply scaling these effective viscosities to larger pipe sizes would provide useful estimates for frictional headlosses. However, the large pipe headlosses are often considerably different than one would predict using this simplistic analysis. Particle migration away from the wall of the pipe during turbulent flow tends to reduce the effective viscosity of the slurry in larger pipes.

The table below gives further evidence to the effectiveness of the hydrotreating process. Centrifuge cake moistures are reported for raw and hydrotreated lignite slurries. In all cases the hydrotreated cakes have considerably less moisture than raw lignite cakes. The small increases in cake moisture of the hydrotreated sample with recirculation time are probably due to the increased difficulty in removing surface moisture as the particles become finer due to attrition in the pipeloop. In summary, the hydrotreating process appears to reduce the lignite's intrinsic moisture in an irreversible manner.

LIGNITE TYPE	PIPELOOP EXPOSURE	CAKE MOISTURE
Raw Conventional	Approx. 1 hr	45.7%
Raw Conventional	Approx. 2 hrs	43.6%
Hydrotreated Conventional	Approx. 1 hr	30.3%
Hydrotreated Conventional	6 hrs	30.9%
Hydrotreated Conventional	54 hrs	31.5%
Hydrotreated/Stabilized	10 hrs	32.7%

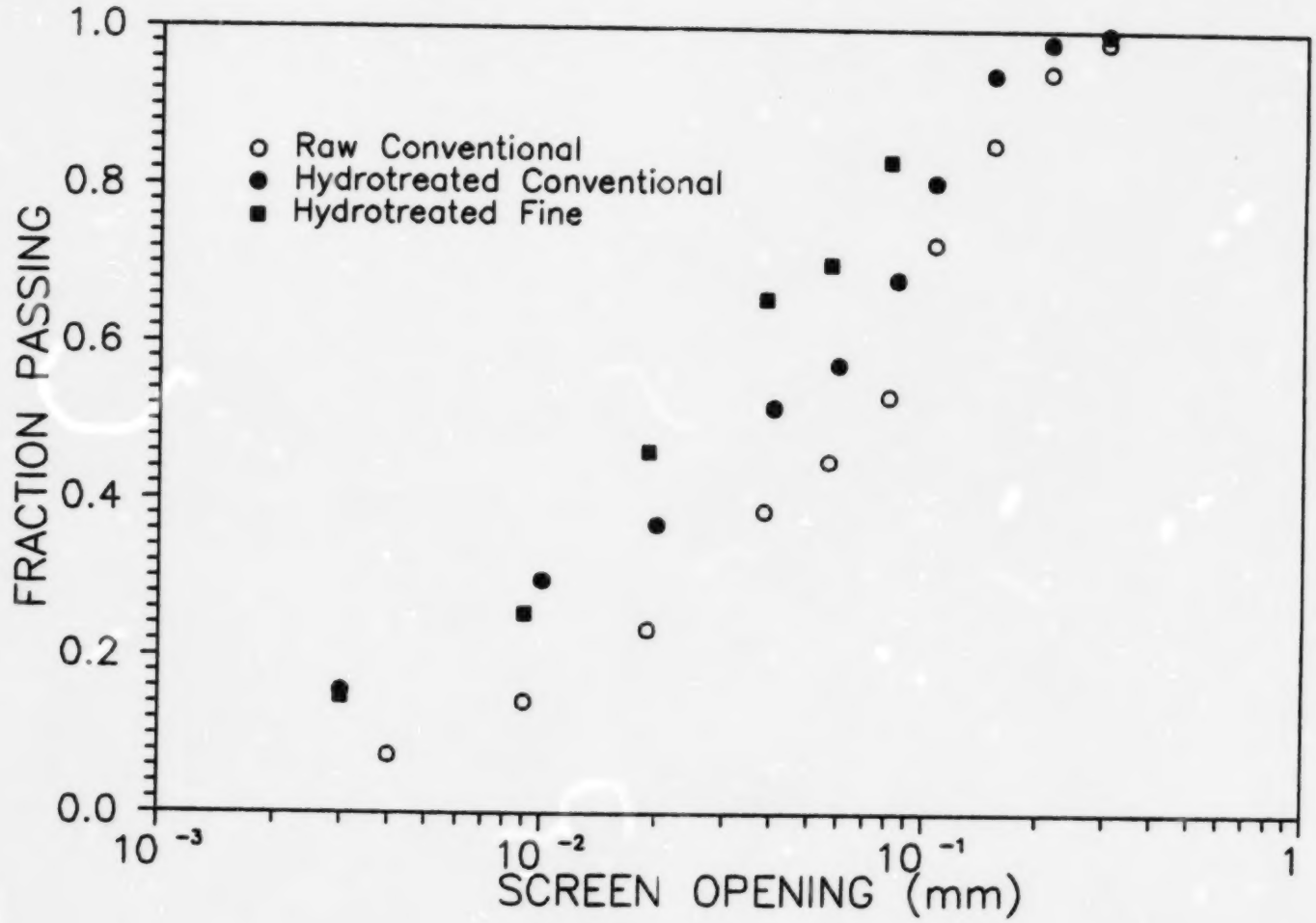
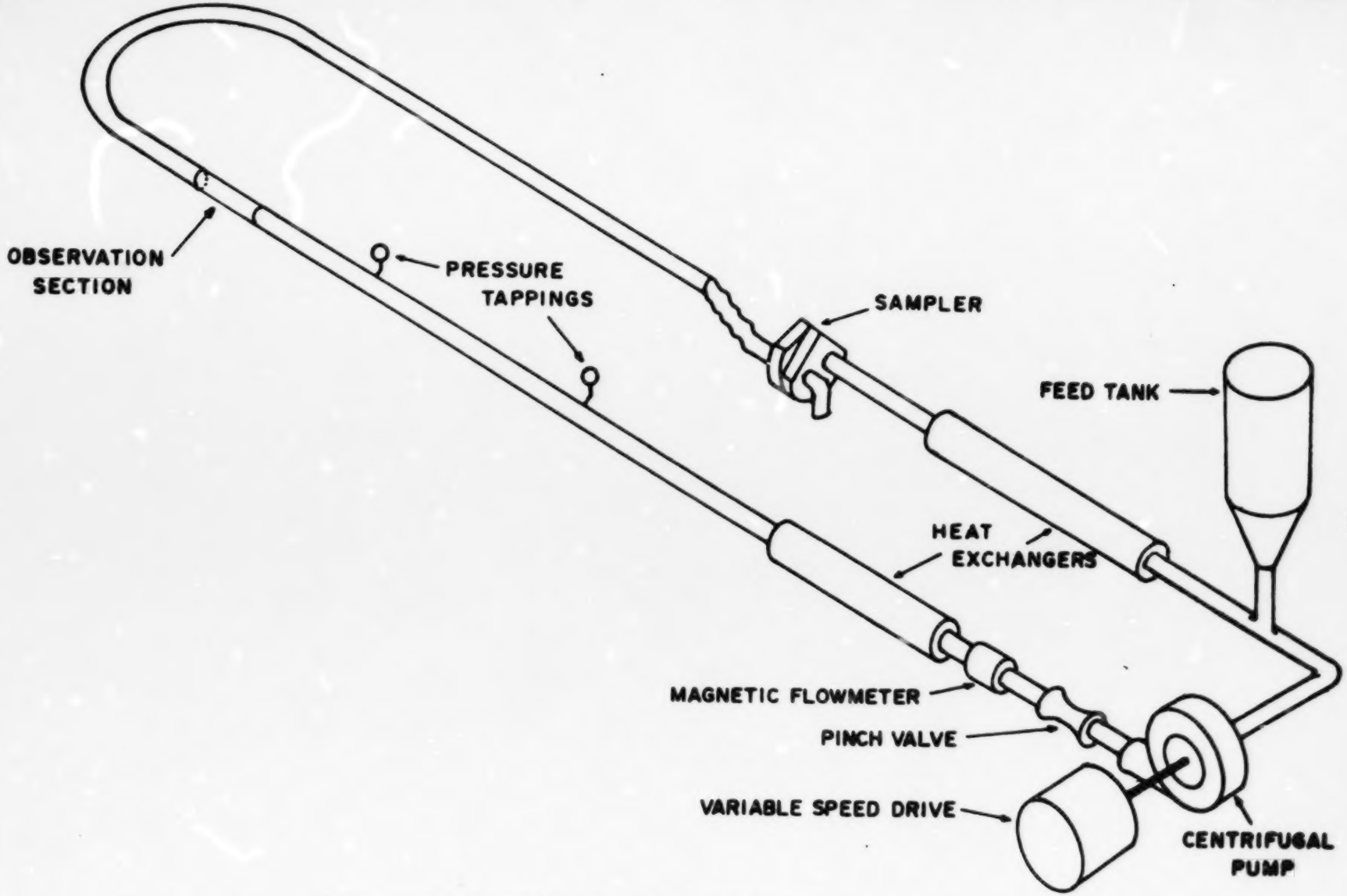


Figure 2: Particle size distributions for lignite samples.



50 mm SLURRY PIPELINE LOOP

Figure 3

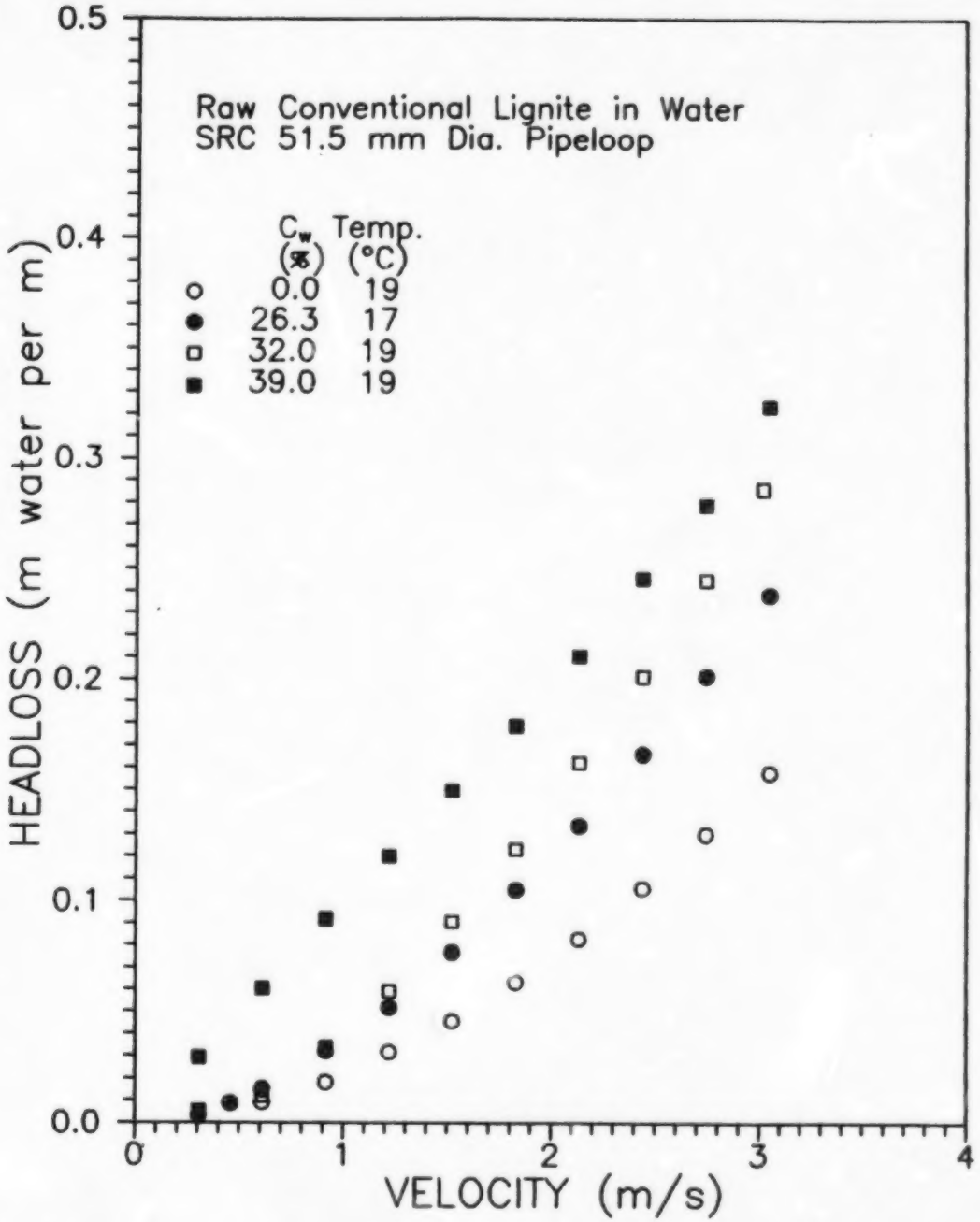


Figure 4: Frictional headloss versus concentration for Saskatchewan lignite slurry.

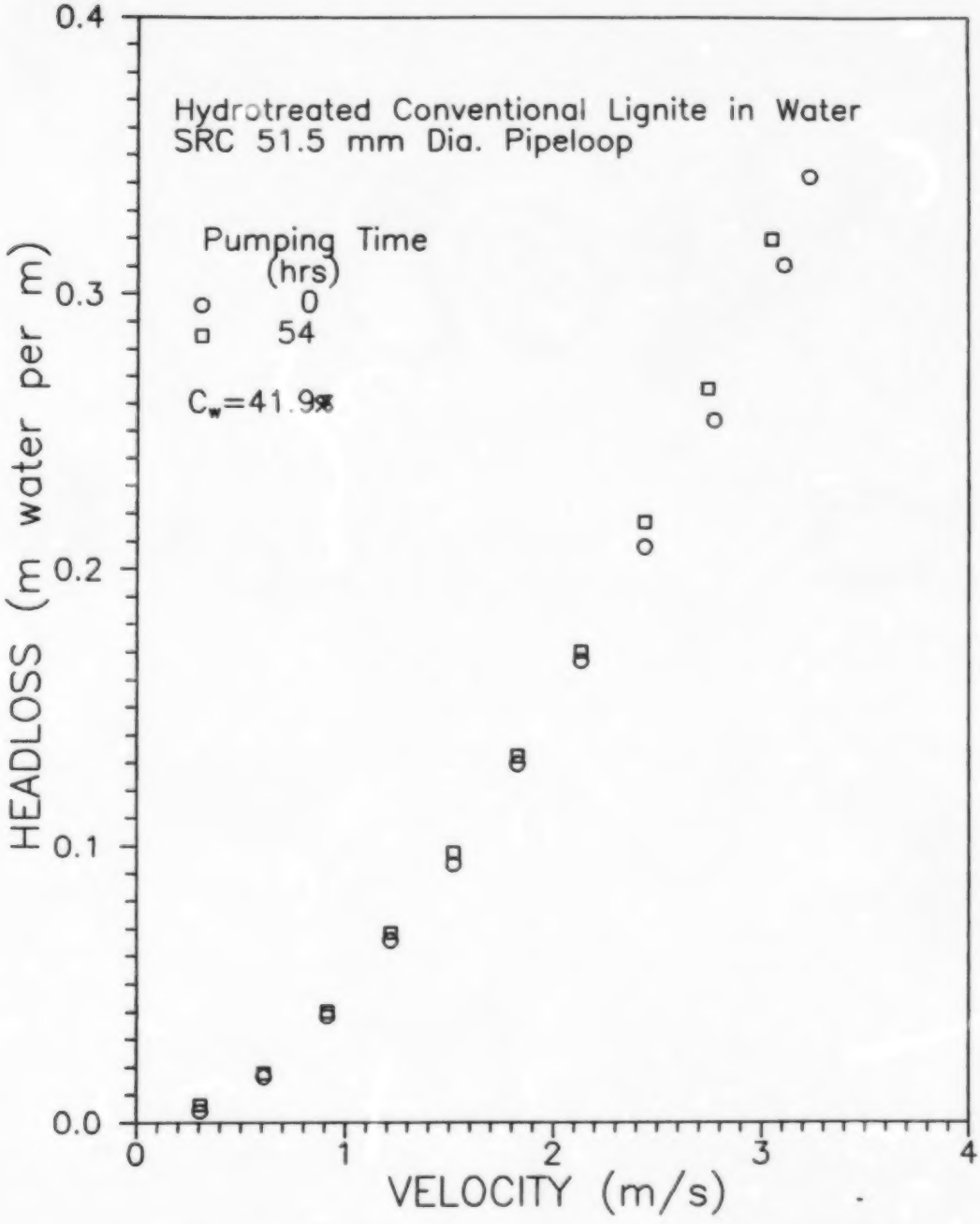


Figure 5: Frictional headloss versus pumping time for Saskatchewan lignite slurry at 20 C.

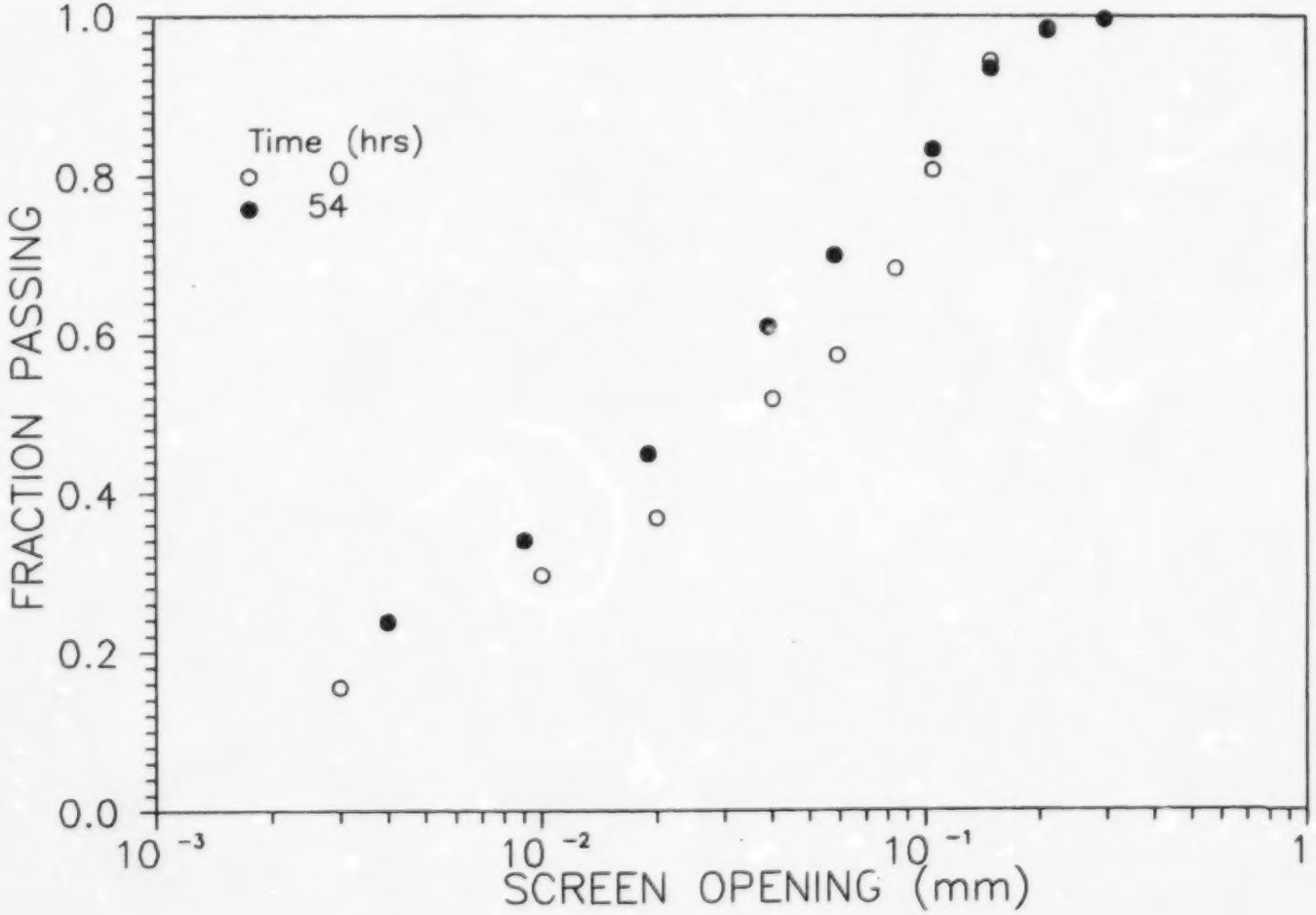


Figure 6: Particle size distribution versus pumping time for conventional hydrotreated lignite slurry.

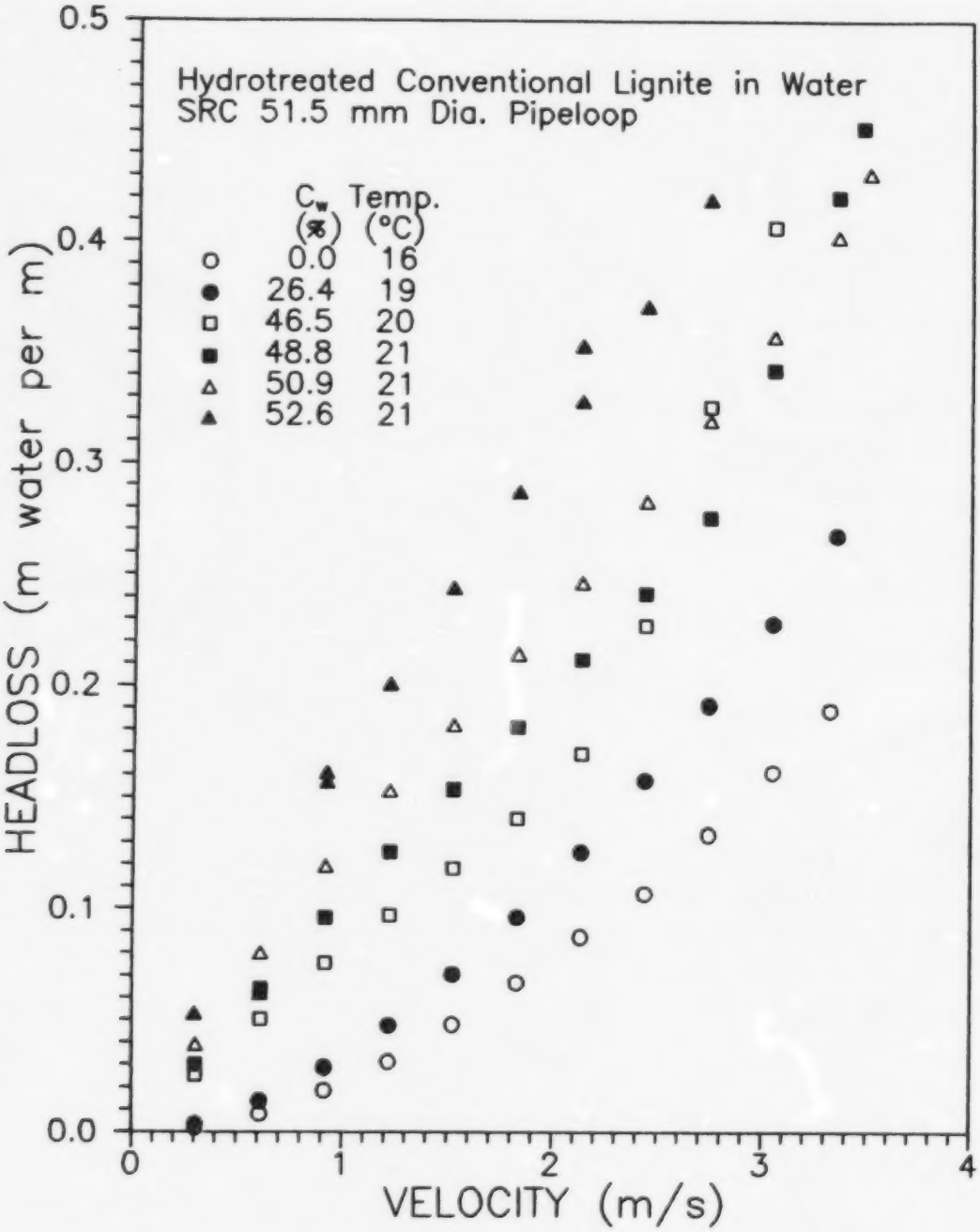


Figure 7: Frictional headloss versus concentration for Saskatchewan lignite slurry.

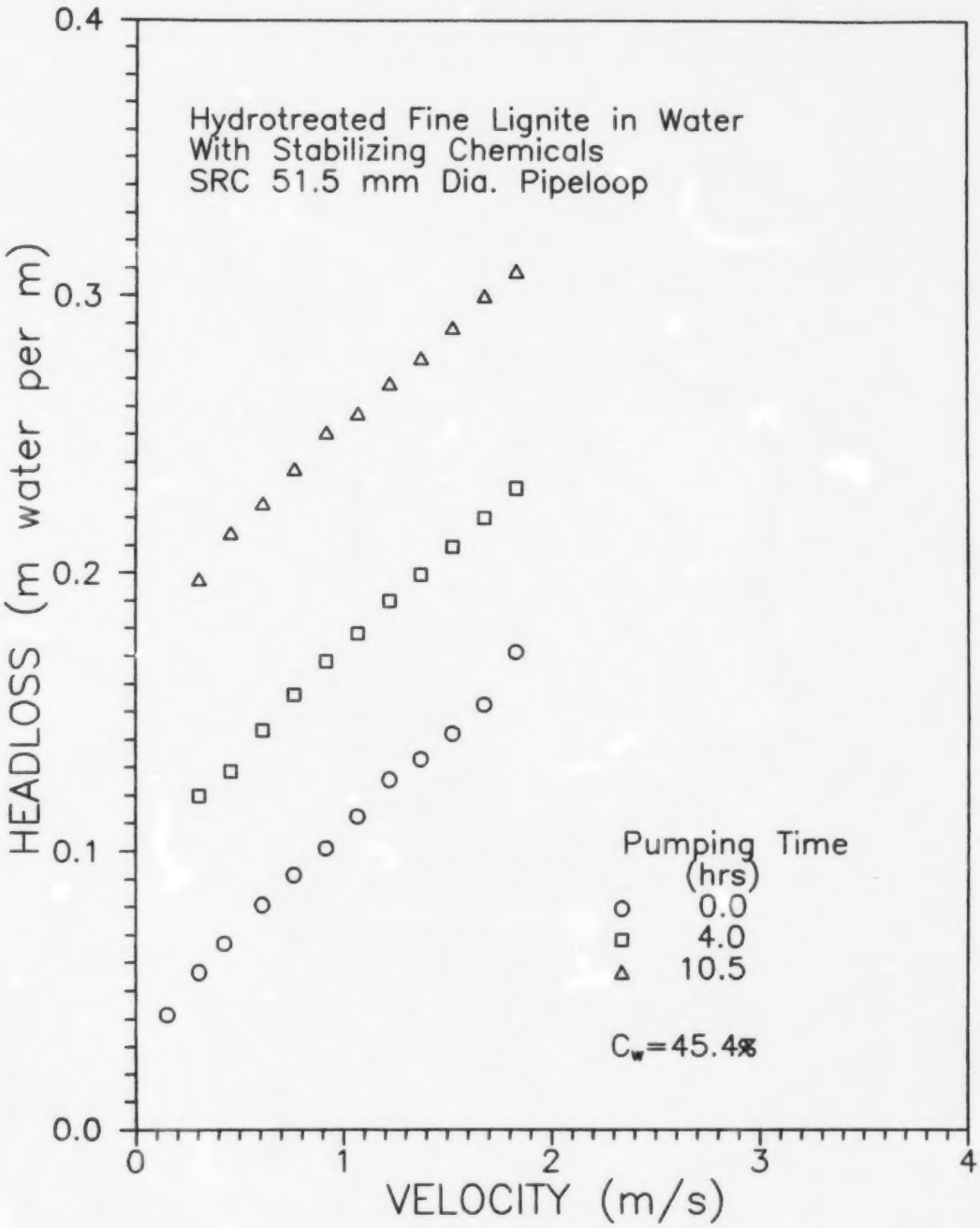


Figure 8: Frictional headloss versus pumping time for Saskatchewan lignite slurry at 19 C.

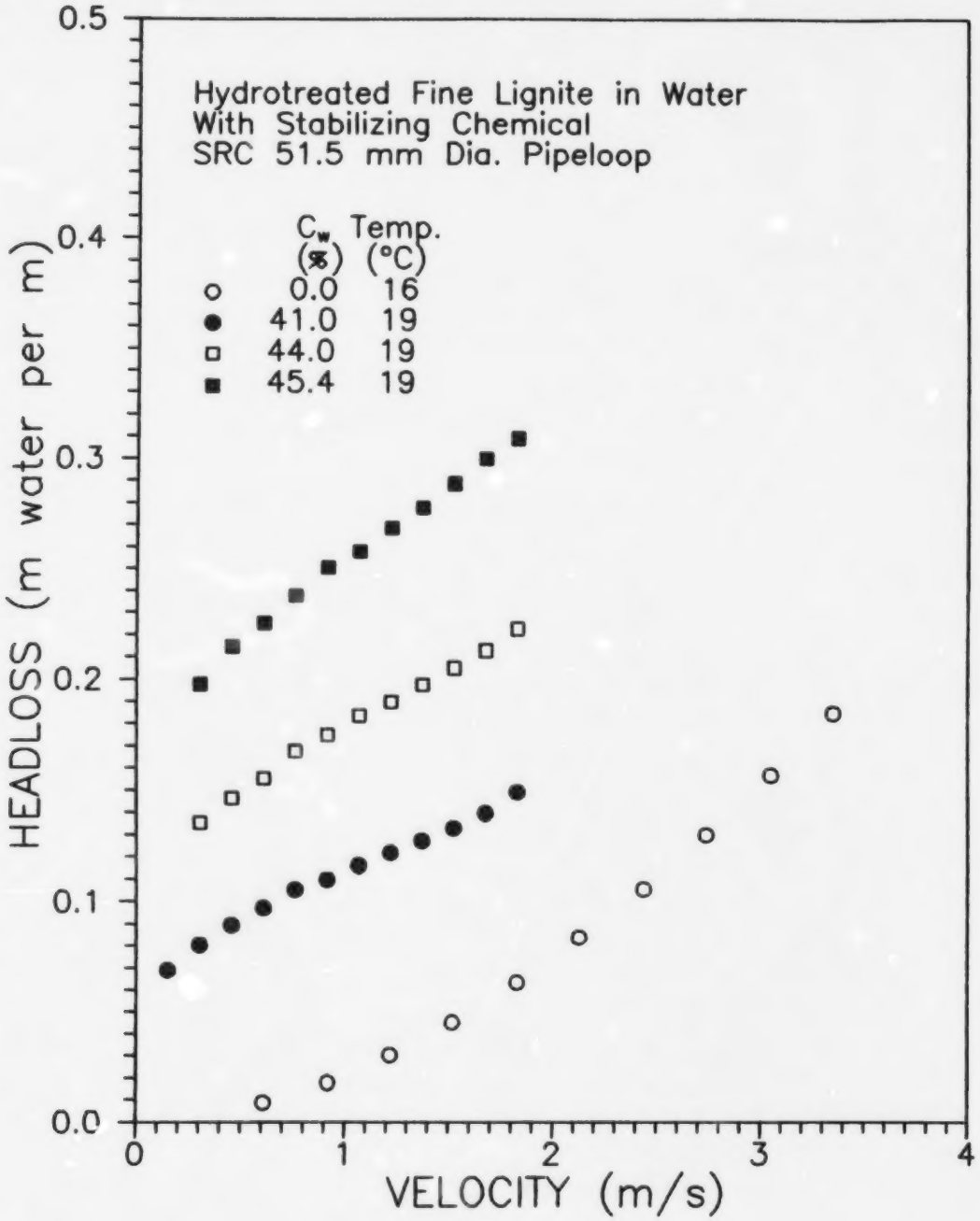


Figure 9: Frictional headloss versus concentration for Saskatchewan lignite slurry.

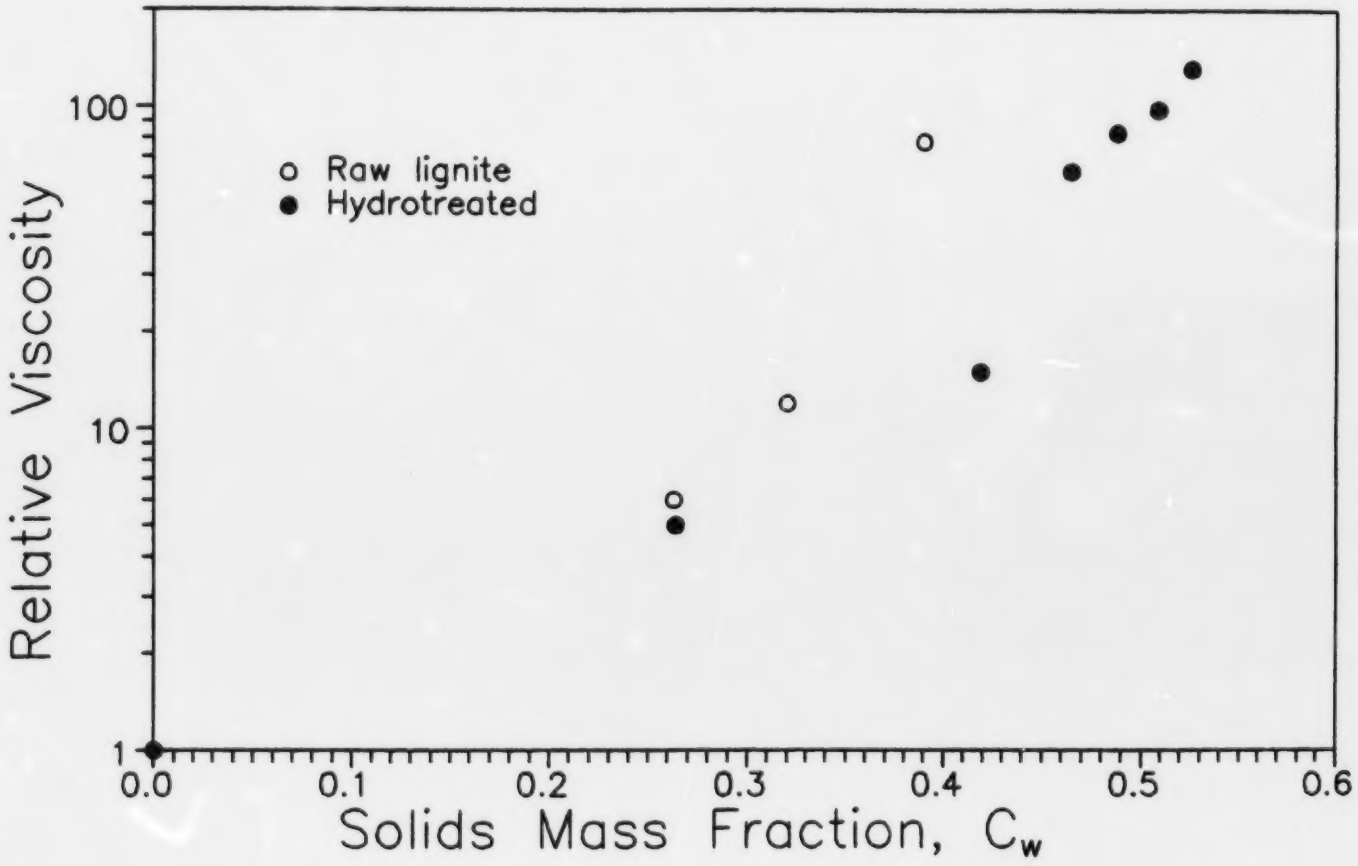


Figure 10: Relative viscosities for conventional lignite slurries as inferred from 50 mm pipeline frictional headlosses

4. CONCLUSIONS AND RECOMMENDATIONS

- All three lignite samples (raw conventional grind, hydrotreated conventional grind and hydrotreated fine grind) produced mixtures which showed homogeneous slurry behaviour in the 50 mm pipeloop.
- The EMRC hydrotreating process effectively improves the pumpability of Saskatchewan lignite slurries by reducing the intrinsic moisture of the coal in an irreversible manner.
- The hydrotreating process significantly improves the energy content of lignite by reducing the moisture remaining in the coal recovered by centrifuging or other separation processes.
- The EMRC stabilizer produced a coal/water fuel which developed a large yield stress and would, therefore, be unsuitable for long distance pipeline transportation.
- It is recommended that an evaluation be carried out to assess the preliminary economics of the hydrotreating process. Assuming favourable results, a large scale upgrading and pipeline testing program is required to fully evaluate the thermal upgrading process.

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APPENDIX A - PIPELOOP DATA

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905050	PIPE DIAMETER (m):	0.0515
DATE:	March 1989	SOLIDS DENSITY (g/cc):	------
TEMP (C):	19	SOLIDS MASS FRACTION:	0.000
CARRIER:	Water	SOLIDS VOL. FRACTION:	0.000
SOLIDS:	-------	SLURRY DENSITY (g/cc)	0.998

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
3.05	0.1578
2.74	0.1299
2.44	0.1056
2.13	0.0825
1.83	0.0631
1.52	0.0455
1.22	0.0316
0.92	0.0181
0.61	0.0091

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905051	PIPE DIAMETER (m):	0.0515
DATE:	March, 1989	SOLIDS DENSITY (g/cc):	1.600
TEMP (C):	17	SOLIDS MASS FRACTION:	0.263
CARRIER:	Water	SOLIDS VOL. FRACTION:	----
SOLIDS:	Raw Convent. Lignite	SLURRY DENSITY (g/cc)	1.108

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
3.05	0.2383
2.74	0.2016
2.44	0.1663
2.13	0.1338
1.83	0.1049
1.52	0.0765
1.22	0.0518
0.92	0.0320
0.61	0.0151
0.46	0.0088
0.31	0.0034

Stationary deposit at 0.31 m/s.

PARTICLE SIZE DISTRIBUTION

SIZE mm	FRACTION PASSING
0.297	0.985
0.210	0.946
0.149	0.854
0.105	0.727
0.080	0.533
0.056	0.450
0.038	0.386
0.019	0.234
0.009	0.142
0.004	0.074

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905052	PIPE DIAMETER (m):	0.0515
DATE:	March, 1989	SOLIDS DENSITY (g/cc):	1.600
TEMP (C):	19	SOLIDS MASS FRACTION:	0.32
CARRIER:	Water	SOLIDS VOL. FRACTION:	----
SOLIDS:	Raw Convent. Lignite	SLURRY DENSITY (g/cc)	1.135

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
3.02	0.2860
2.74	0.2451
2.44	0.2015
2.13	0.1622
1.83	0.1233
1.52	0.0903
1.22	0.0589
0.92	0.0338
0.61	0.0118
0.31	0.0056

Stationary solids deposit at 0.31 m/s.

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905053		
DATE:	March, 1989	PIPE DIAMETER (m):	0.0515
TEMP (C):	19	SOLIDS DENSITY (g/cc):	1.600
CARRIER:	Water	SOLIDS MASS FRACTION:	0.390
SOLIDS:	Raw Convent. Lignite	SOLIDS VOL. FRACTION:	----
		SLURRY DENSITY (g/cc)	1.170

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
3.05	0.3236
2.74	0.2788
2.44	0.2456
2.13	0.2106
1.83	0.1790
1.52	0.1499
1.22	0.1199
0.92	0.0915
0.61	0.0602
0.31	0.0291

No solids deposit detected.

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905010	PIPE DIAMETER (m):	0.0515
DATE:	February, 1989	SOLIDS DENSITY (g/cc):	------
TEMP (C):	16	SOLIDS MASS FRACTION:	0.000
CARRIER:	Water	SOLIDS VOL. FRACTION:	0.000
SOLIDS:	-------	SLURRY DENSITY (g/cc)	0.998

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
3.32	0.1894
3.05	0.1616
2.74	0.1335
2.44	0.1068
2.13	0.0874
1.83	0.0667
1.52	0.0481
1.22	0.0314
0.92	0.0185
0.61	0.0082
0.31	0.0019

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905012	PIPE DIAMETER (m):	0.0515
DATE:	February, 1989	SOLIDS DENSITY (g/cc):	1.510
TEMP (C):	19	SOLIDS MASS FRACTION:	0.419
CARRIER:	Water	SOLIDS VOL. FRACTION:	----
SOLIDS:	Hydrotreated Conv. Lign.	SLURRY DENSITY (g/cc)	1.163

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
3.23	0.3419
3.11	0.3101
2.77	0.2537
2.44	0.2079
2.13	0.1670
1.83	0.1297
1.52	0.0934
1.22	0.0656
0.92	0.0382
0.61	0.0166
0.31	0.0041

PARTICLE SIZE DISTRIBUTION

SIZE mm	FRACTION PASSING
0.297	0.996
0.210	0.984
0.149	0.943
0.105	0.806
0.084	0.682
0.059	0.573
0.040	0.518
0.020	0.368
0.010	0.296
0.003	0.156

Headloss at beginning of long duration test.

No deposit detected.

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905013	PIPE DIAMETER (m):	0.0515
DATE:	February, 1989	SOLIDS DENSITY (g/cc):	1.510
TEMP (C):	20	SOLIDS MASS FRACTION:	0.419
CARRIER:	Water	SOLIDS VOL. FRACTION:	----
SOLIDS:	Hydrotreated Conv. Lign.	SLURRY DENSITY (g/cc)	1.163

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
3.05	0.3194
2.74	0.2654
2.44	0.2169
2.13	0.1702
1.83	0.1324
1.52	0.0974
1.22	0.0685
0.92	0.0399
0.61	0.0178
0.31	0.0063

PARTICLE SIZE DISTRIBUTION

SIZE mm	FRACTION PASSING
0.297	0.996
0.210	0.982
0.149	0.934
0.105	0.832
0.058	0.699
0.039	0.609
0.019	0.449
0.009	0.340
0.004	0.238

Headloss after 54 hours of recirculation.

No deposit detected.

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905015	PIPE DIAMETER (m):	0.0515
DATE:	February, 1989	SOLIDS DENSITY (g/cc):	1.510
TEMP (C):	21	SOLIDS MASS FRACTION:	0.526
CARRIER:	Water	SOLIDS VOL. FRACTION:	----
SOLIDS:	Hydrotreated Conv. Lign.	SLURRY DENSITY (g/cc)	1.215

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
2.74	0.4190
2.44	0.3710
2.13	0.3280
1.83	0.2870
1.52	0.2440
1.22	0.2010
0.92	0.1570
0.61	0.0620
0.30	0.0530
0.92	0.1610
2.13	0.3530

No deposit detected.

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905017	PIPE DIAMETER (m):	0.0515
DATE:	February, 1989	SOLIDS DENSITY (g/cc):	1.510
TEMP (C):	21	SOLIDS MASS FRACTION:	0.509
CARRIER:	Water	SOLIDS VOL. FRACTION:	----
SOLIDS:	Hydrotreated Conv. Lign.	SLURRY DENSITY (g/cc)	1.206

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
3.51	0.4310
3.35	0.4023
3.05	0.3574
2.74	0.3194
2.44	0.2828
2.13	0.2466
1.83	0.2145
1.52	0.1825
1.22	0.1529
0.92	0.1193
0.61	0.0800
0.31	0.0391

No deposit detected.

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905018	PIPE DIAMETER (m):	0.0515
DATE:	February, 1989	SOLIDS DENSITY (g/cc):	1.510
TEMP (C):	21	SOLIDS MASS FRACTION:	0.488
CARRIER:	Water	SOLIDS VOL. FRACTION:	----
SOLIDS:	Hydrotreated Conv. Lign.	SLURRY DENSITY (g/cc)	1.196

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
3.47	0.4518
3.35	0.4204
3.05	0.3421
2.74	0.2756
2.44	0.2417
2.13	0.2120
1.83	0.1817
1.52	0.1536
1.22	0.1255
0.92	0.0959
0.61	0.0638
0.31	0.0301

No deposit detected.

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905019	PIPE DIAMETER (m):	0.0515
DATE:	February, 1989	SOLIDS DENSITY (g/cc):	1.510
TEMP (C):	20	SOLIDS MASS FRACTION:	0.465
CARRIER:	Water	SOLIDS VOL. FRACTION:	----
SOLIDS:	Hydrotreated Conv. Lign.	SLURRY DENSITY (g/cc)	1.185

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
3.05	0.4066
2.74	0.3256
2.44	0.2275
2.13	0.1698
1.83	0.1407
1.52	0.1183
1.22	0.0971
0.92	0.0755
0.61	0.0504
0.31	0.0255

No deposit detected.

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905020	PIPE DIAMETER (m):	0.0515
DATE:	February, 1989	SOLIDS DENSITY (g/cc):	1.510
TEMP (C):	19	SOLIDS MASS FRACTION:	0.264
CARRIER:	Water	SOLIDS VOL. FRACTION:	----
SOLIDS:	Hydrotreated Conv. Lign.	SLURRY DENSITY (g/cc)	1.096

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
3.35	0.2678
3.05	0.2284
2.74	0.1916
2.44	0.1580
2.13	0.1257
1.83	0.0963
1.52	0.0705
1.22	0.0477
0.92	0.0286
0.61	0.0139
0.31	0.0035

No deposit detected.

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905040	PIPE DIAMETER (m):	0.0515
DATE:	March, 1989	SOLIDS DENSITY (g/cc):	----
TEMP (C):	16	SOLIDS MASS FRACTION:	0.000
CARRIER:	Water	SOLIDS VOL. FRACTION:	0.000
SOLIDS:	-----	SLURRY DENSITY (g/cc)	0.999

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
3.35	0.1850
3.05	0.1570
2.74	0.1300
2.44	0.1055
2.13	0.0839
1.83	0.0634
1.52	0.0453
1.22	0.0304
0.92	0.0179
0.61	0.0088

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905042	PIPE DIAMETER (m):	0.0515
DATE:	March, 1989	SOLIDS DENSITY (g/cc):	1.510
TEMP (C):	19	SOLIDS MASS FRACTION:	0.454
CARRIER:	Water	SOLIDS VOL. FRACTION:	----
SOLIDS:	Hydrotreated Fine Lign.	SLURRY DENSITY (g/cc)	1.180

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
1.83	0.1719
1.68	0.1529
1.52	0.1424
1.37	0.1333
1.22	0.1258
1.07	0.1125
0.92	0.1012
0.76	0.0915
0.61	0.0807
0.43	0.0668
0.31	0.0565
0.15	0.0413

PARTICLE SIZE DISTRIBUTION

SIZE mm	FRACTION PASSING
0.080	0.832
0.056	0.701
0.038	0.656
0.019	0.461
0.009	0.254
0.003	0.148

Headloss at start of long duration test.

No deposit detected.

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905044	PIPE DIAMETER (m):	0.0515
DATE:	March, 1989	SOLIDS DENSITY (g/cc):	1.510
TEMP (C):	19	SOLIDS MASS FRACTION:	0.454
CARRIER:	Water	SOLIDS VOL. FRACTION:	----
SOLIDS:	Hydrotreated Fine Lign.	SLURRY DENSITY (g/cc)	1.180

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
1.83	0.2308
1.68	0.2202
1.52	0.2097
1.37	0.1995
1.22	0.1900
1.07	0.1784
0.92	0.1682
0.76	0.1560
0.61	0.1432
0.46	0.1286
0.31	0.1198

Headloss after 4 hours of recirculation.

No deposit detected.

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905045	PIPE DIAMETER (m):	0.0515
DATE:	March, 1989	SOLIDS DENSITY (g/cc):	1.510
TEMP (C):	19	SOLIDS MASS FRACTION:	0.454
CARRIER:	Water	SOLIDS VOL. FRACTION:	----
SOLIDS:	Hydrotreated Fine Lign.	SLURRY DENSITY (g/cc)	1.180

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
1.83	0.3090
1.68	0.2998
1.52	0.2885
1.37	0.2775
1.22	0.2684
1.07	0.2575
0.92	0.2504
0.76	0.2374
0.61	0.2251
0.46	0.2144
0.31	0.1977

Headloss after 10 hours of recirculation.

No deposit detected.

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905046	PIPE DIAMETER (m):	0.0515
DATE:	March, 1989	SOLIDS DENSITY (g/cc):	1.510
TEMP (C):	19	SOLIDS MASS FRACTION:	0.41
CARRIER:	Water	SOLIDS VOL. FRACTION:	----
SOLIDS:	Hydrotreated Fine Lign.	SLURRY DENSITY (g/cc)	1.159

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
1.83	0.1494
1.68	0.1397
1.52	0.1330
1.37	0.1274
1.22	0.1218
1.07	0.1160
0.92	0.1098
0.76	0.1052
0.61	0.0969
0.46	0.0893
0.31	0.0802
0.15	0.0687

No deposit detected.

SASKATCHEWAN RESEARCH COUNCIL PIPELINE TECHNOLOGY CENTRE

RUN #:	8905047	PIPE DIAMETER (m):	0.0515
DATE:	March, 1989	SOLIDS DENSITY (g/cc):	1.510
TEMP (C):	19	SOLIDS MASS FRACTION:	0.44
CARRIER:	Water	SOLIDS VOL. FRACTION:	----
SOLIDS:	Hydrotreated Fine Lign.	SLURRY DENSITY (g/cc)	1.173

PIPELINE PERFORMANCE

VELOCITY m/s	HEADLOSS m water/m
1.83	0.2227
1.68	0.2129
1.52	0.2051
1.37	0.1975
1.22	0.1897
1.07	0.1836
0.92	0.1750
0.76	0.1677
0.61	0.1555
0.46	0.1464
0.31	0.1356

No deposit detected.

APPENDIX B - EMRC HYDROTREATING PROCESS

Energy & Mineral Research Center

Fuels & Process Chemistry Research Institute
ND Mining & Mineral Resources Research Institute
Combustion & Environmental Systems Research Institute

Box 8213, University Station / Grand Forks, North Dakota 58202 / Phone: (701) 777-5000 / Fax: 777-5181

January 5, 1989

Mr. Mike Small
Research Specialist
Saskatchewan Research Council
15 Innovation Blvd.
Saskatoon, Saskatchewan S7N 2X8
CANADA

Dear Mike:

This letter serves to inform you that two drums of raw Saskatchewan lignite and two drums of product coal/water fuel have been sent collect to the Saskatchewan Research Council pipe-loop testing facility. This was prepared from the delivered coal sample from the Coronach Mine near Estevan, Saskatchewan. Ash, moisture, and particle size analysis of the feed and product coal are shown in Table 1 of enclosure. Rheological analyses are also included for the fuels, depicted as apparent viscosity versus shear rate and apparent viscosity versus solids content, as performed on a Haake RV100 viscometer. This is shown on the enclosed graphs.

One sample of the coal was pulverized to the largest size which could be fed into the Energy and Mineral Research Center (EMRC) 2.2 metric ton/day hydrothermal Process Development Unit (PDU), which was determined to be an average size of 71 microns with a top size of over 564 microns. A drum (over 140 kg.) of raw coal at the stated coarse feed size was saved for shipment to SRC. The particle size was slightly lower than for grinding results from previous work. This is not surprising due to the friable nature of lignitic coal. The coal sample was hydrothermally treated at the optimum conditions of 330°C and 140 bar (2200 psi) for a residence time of 5 minutes. No feed problems occurred during the processing. Approximately 8 wt% of the feed coal was lost to process gas, etc., during the processing. The particle size of the coal was lowered to an average size of 36 microns after processing.

The dilute process slurry (approx. 45 wt% dry solids) was concentrated to a moist cake (64 wt% dry solids) using a solid-bowl centrifuge. No wash water was used during the centrifuging. Centrate water used during centrifuging contained 10 wt% dry solids of the coal fed. An overall process recovery of 82 wt% dry coal was realized. The ash content was only slightly lower than the raw coal. The coal product was to be sent as a moist cake, as originally agreed. However, after careful observation, it was determined that the cake was extremely susceptible to biological degradation. Therefore, the cake was mixed into a concentrated coal/water mixture of 58.7 wt% dry solids. An amount of 0.1 wt% formaldehyde was added as a preservative to the

CWF for shipment and storage.

The particle packing efficiency (broader PSD) of the larger sized coal product was more effective in achieving a higher solids content in the fuel than in the blended sample. Routine rheological analysis of the raw grind and the product to generate a relationship between apparent viscosity and solids content is shown in the enclosed figures. Note higher solids content for a comparable viscosity for the larger grind, -200 mesh (-74 μm) sample than for the -325 mesh sample. The 200 mesh preparation represents a preparation scenario requiring the least cost to produce a combustible CWF from Saskatchewan lignite by hot-water drying. The addition of a low-cost dispersant additive, such as ALS 268-7, to this fuel would further enhance the solids content. A stabilizer would be ineffective with the sample due to the larger size particles and is not recommended.

For the second CWF, a sample of crushed Saskatchewan coal was pulverized to a 41 micron average particle size and hydrothermally treated according to the same conditions described for the larger coal feed. The hydrothermally treated process slurry was centrifuged to a moist cake with 2 gallon/minute wash water. This resulted in a lower ash content, 9.2 dry wt%, than for the unwashed product ash level of 12.9 dry wt%. The particle size distribution (PSD) was reduced to an average size of 29 μm after processing. A near optimum PSD was achieved by blending of a micronized (11 micron) portion of the coal product produced in a continuous wet grinder with the 29 micron material at a 1 to 5 ratio. It would have been desirable to grind the micronized portion finer than that attained to achieve a better bimodal mixture, yet further grinding of the coal proved to be ineffective.

Additives were used to increase the solids loading and increase the stability of the final CWF. Additives included 1.0 wt% of ammonium lignosulfonate (ALS 268-7 from the Reed-Lignin Co., Quebec City, Quebec, Canada) and 0.2 wt% xanthan gum (Pfizer Chemical Co., Groton, Connecticut, USA). The stabilizer should allow 3 to 6 month storage stability. Note the penalty in solids loading realized when the stabilizer is added, as shown in the apparent viscosity versus solids content figure. The cost of the additives used is $0.05/lb., FOB Quebec City, for the ALS 268-7 and the cost for the xanthan gum is $0.20/lb., FOB Groton, Conn.

The fuels all exhibited pseudoplastic (shear-thinning) flow behavior, as shown in the enclosed figures. The pseudoplastic effect for the blended fuel was decreased when the stabilizer was added to the CWF.

One drum of each sample of coal product prepared has been shipped to your attention. Samples of the fuel have been pulled from the drums of the CWF for your initial convenience. In addition, two samples of the CWF have been pulled and labeled for shipment as a courtesy to Saskatchewan Energy and Mines. It would be appreciated if the Saskatchewan Research Council would send these samples and a copy of this correspondence to Dr. Malcolm Wilson, Project Director, Saskatchewan Energy and Mines, 1914 Hamilton St. in Regina, if this is acceptable to SRC and your respective client(s).

It is hoped that the completed coal and CWF preparation is adequate for

your research needs. If you have any further questions, please call. Thanks again for your visit and your timely and responsible delivery of the coal sample. We would appreciate hearing of your results and look forward to working with you again in the future.

Sincerely,

Todd Potas

Todd A. Potas
Research Supervisor
Low-Rank Coal Beneficiation

TAP/cac

Enclosures

c: Randy Gillies, Project Manager, SRC
Everett Sondreal

Table 1. Various Saskatchewan Lignite Raw and Product Coal Characteristics

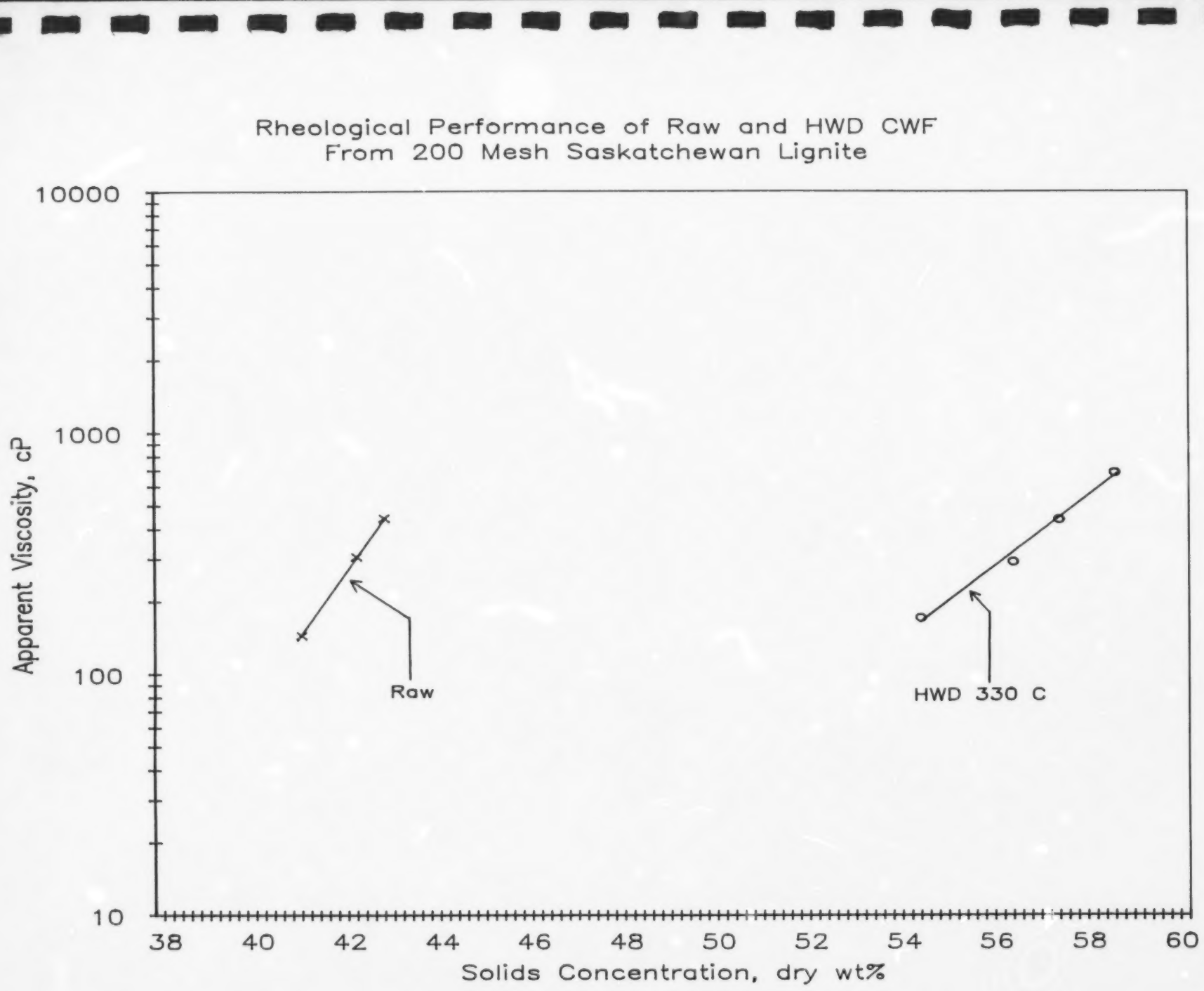
Sample Type	Solids Content (dry wt%)	Ash Content (dry wt%)	Average Particle Size (microns)
Raw Pulverized Coal			
(-74 um)	68.0	14.0	71
(-44 um)	68.0	14.0	41
CWF Product			
(-74 um, unwashed)	58.7	12.9	36
(-44 um, washed)	53.5	9.2	29
(80/20 blend w/ add.)	55.5	9.2	24

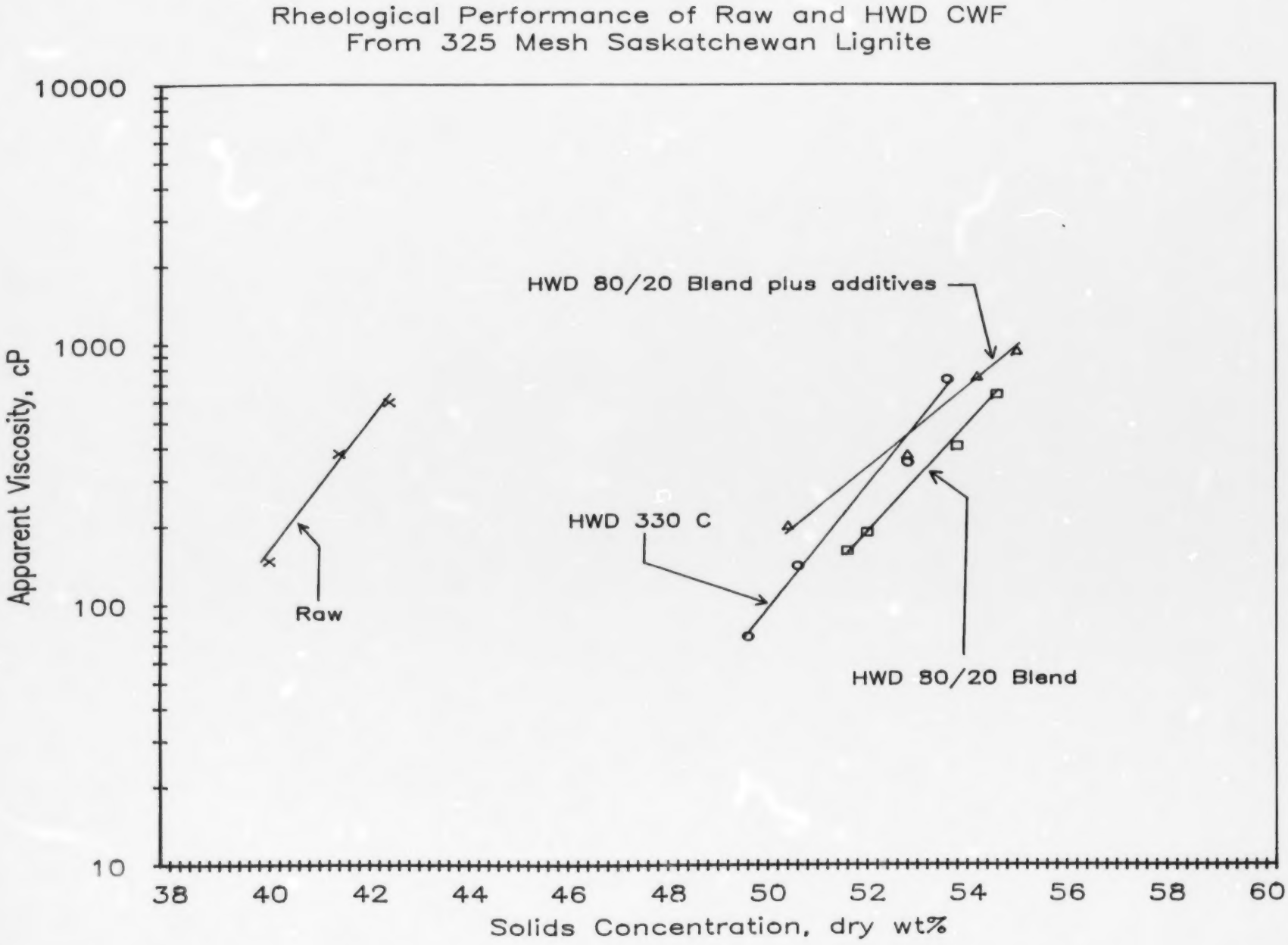
* Centrifuge solids recovery = 88 wt%, 12 wt% in centrate

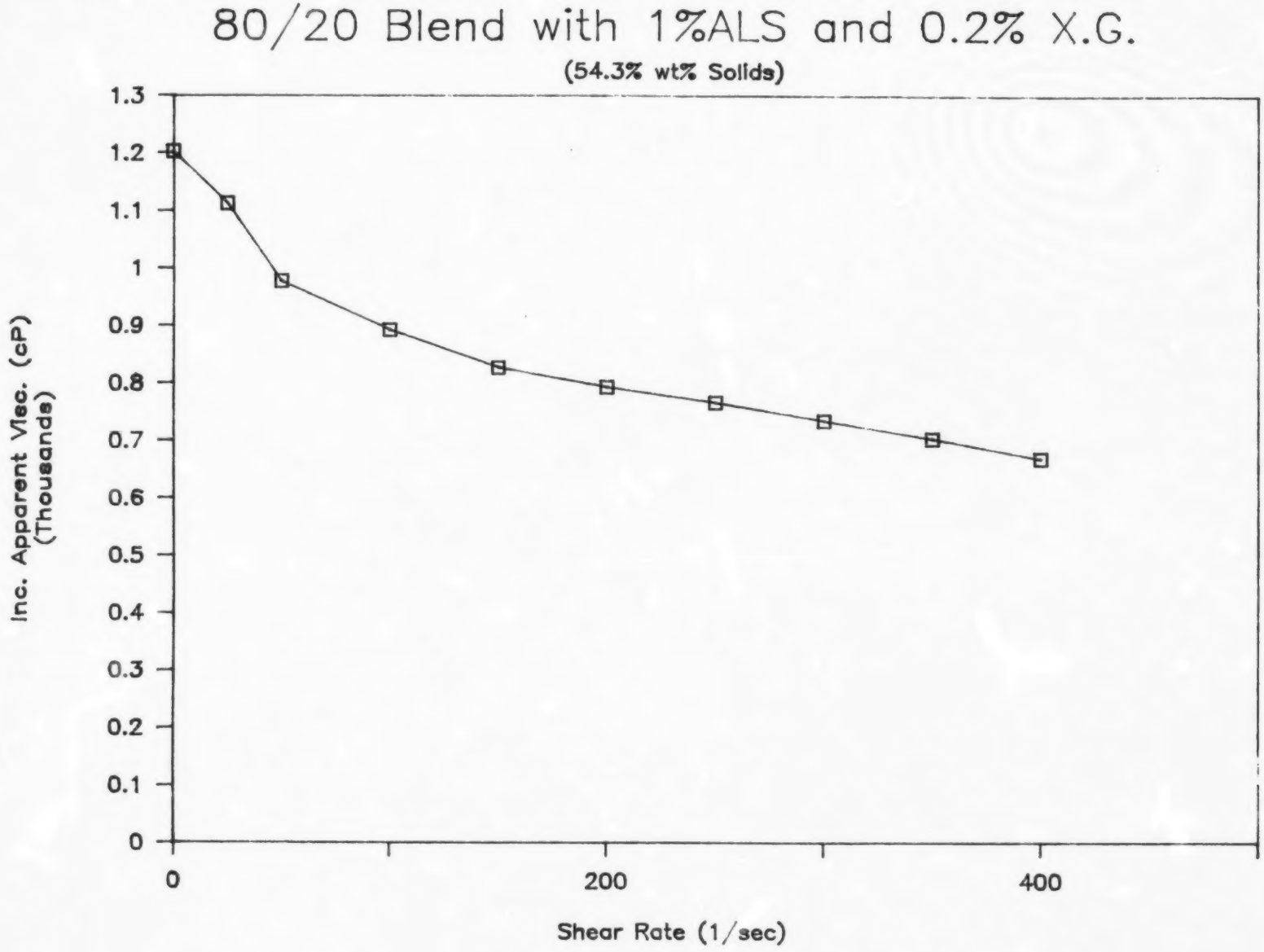
** Process solids recovery = 92 wt%, 8 wt% converted to gas

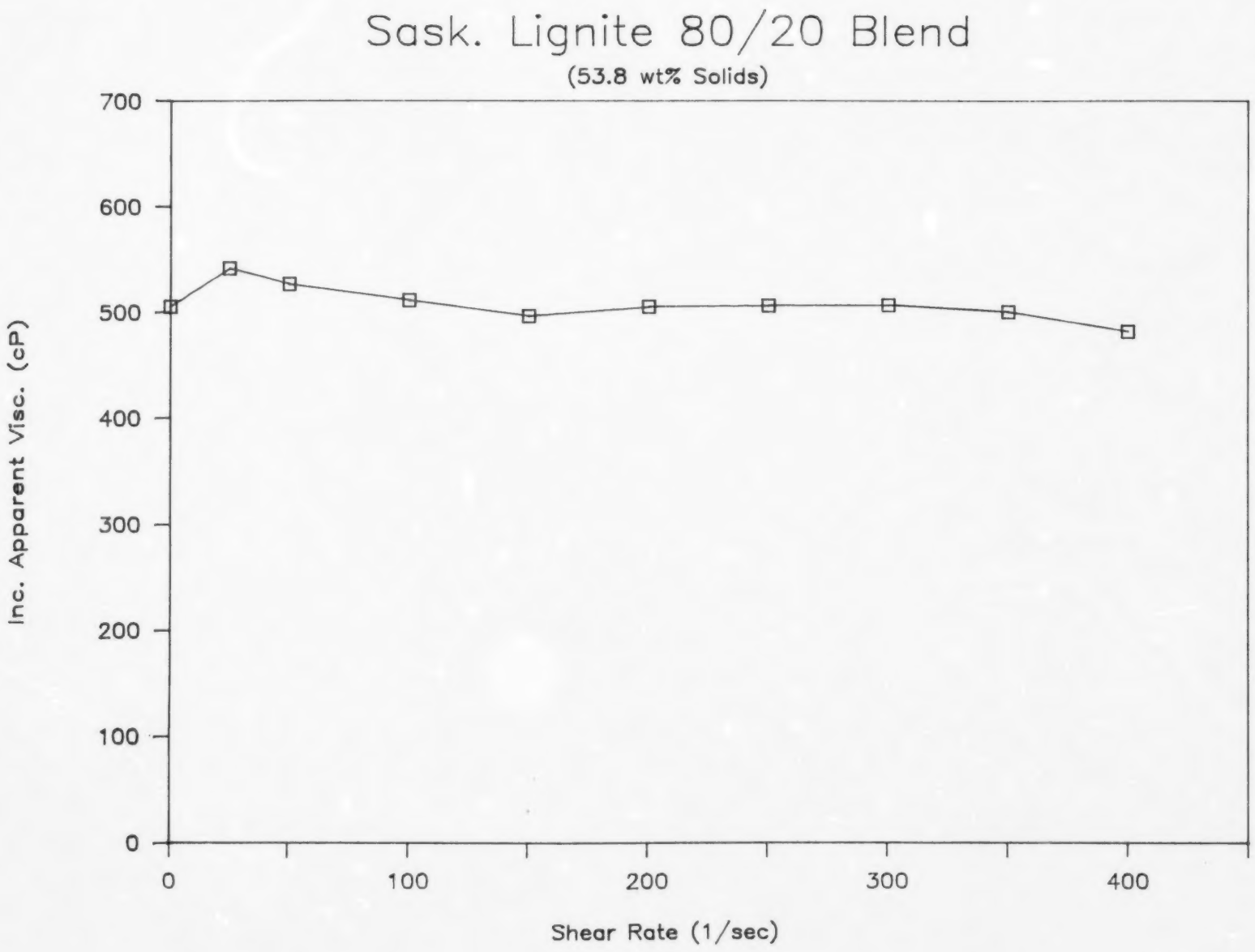
*** Overall solids recovery = 80 wt%

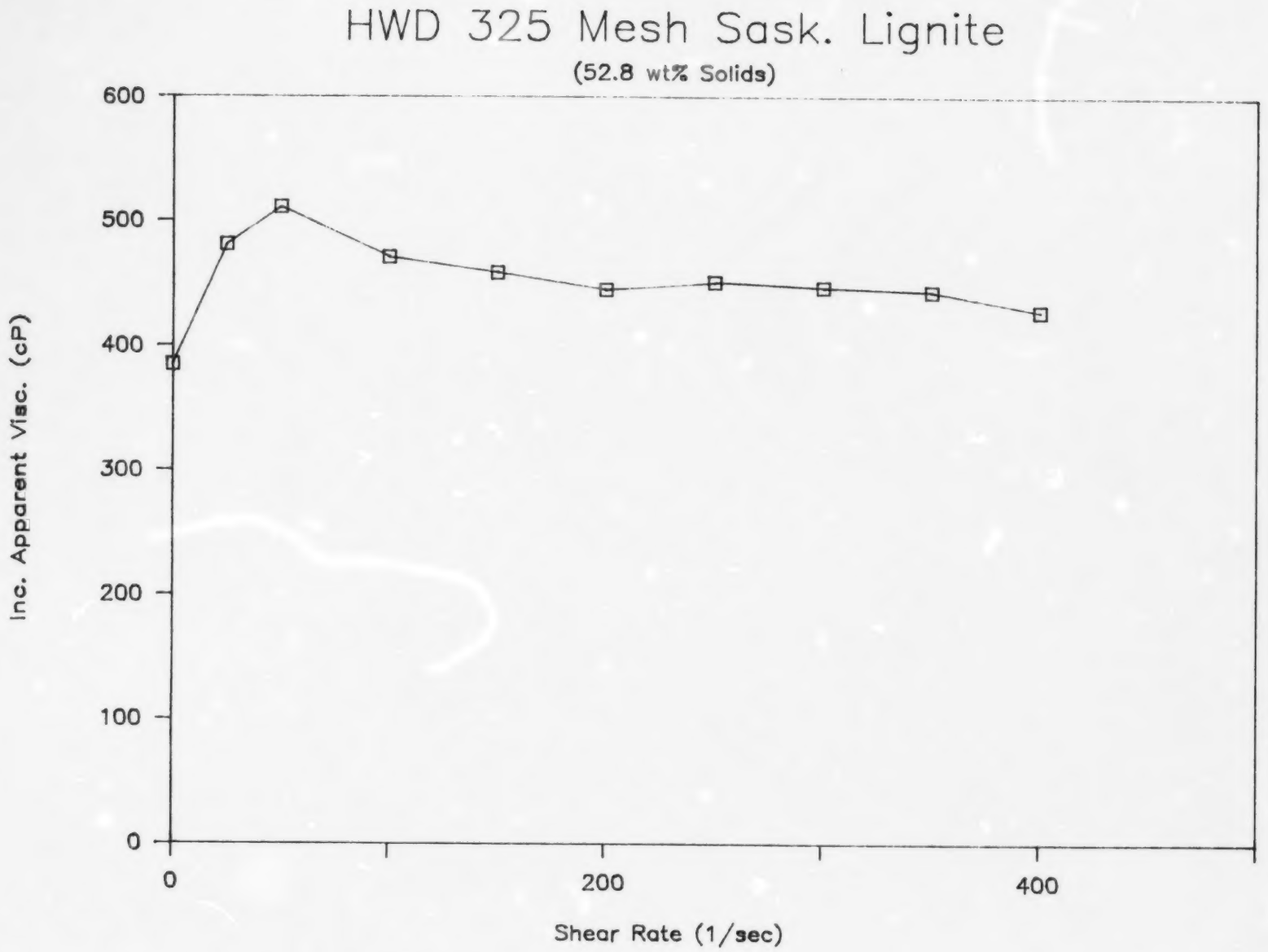
**** Energy recovery balance is higher due to increased energy density of the product solid and higher percent ash in centrate solids lost.

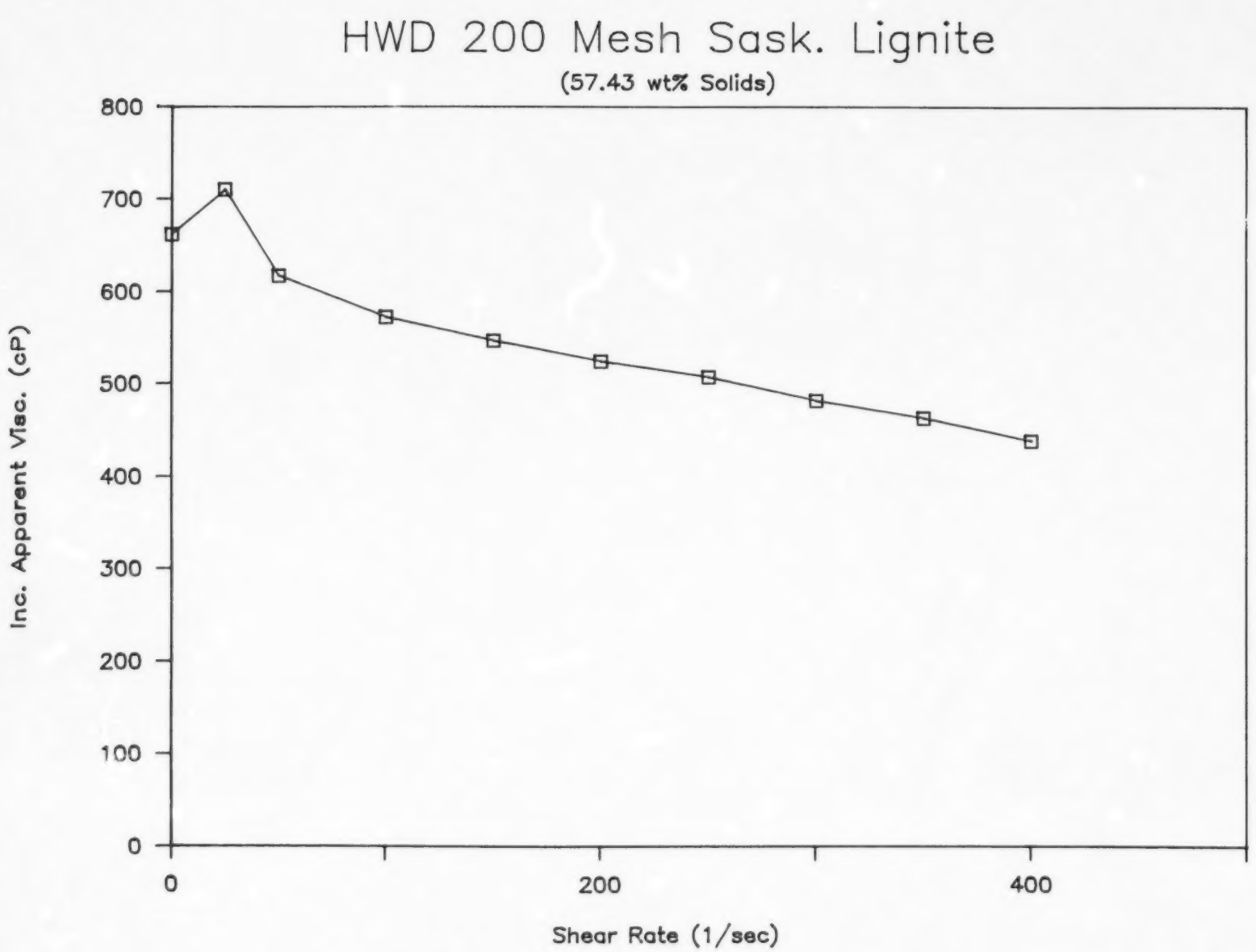

Rheological Performance of Raw and HWD CWF
From 200 Mesh Saskatchewan Lignite
10000
1000
100
10
Apparent Viscosity, cP
Raw
HWD 330 C
38
40
42
44
46
48
50
52
54
56
58
60
Solids Concentration, dry wt%

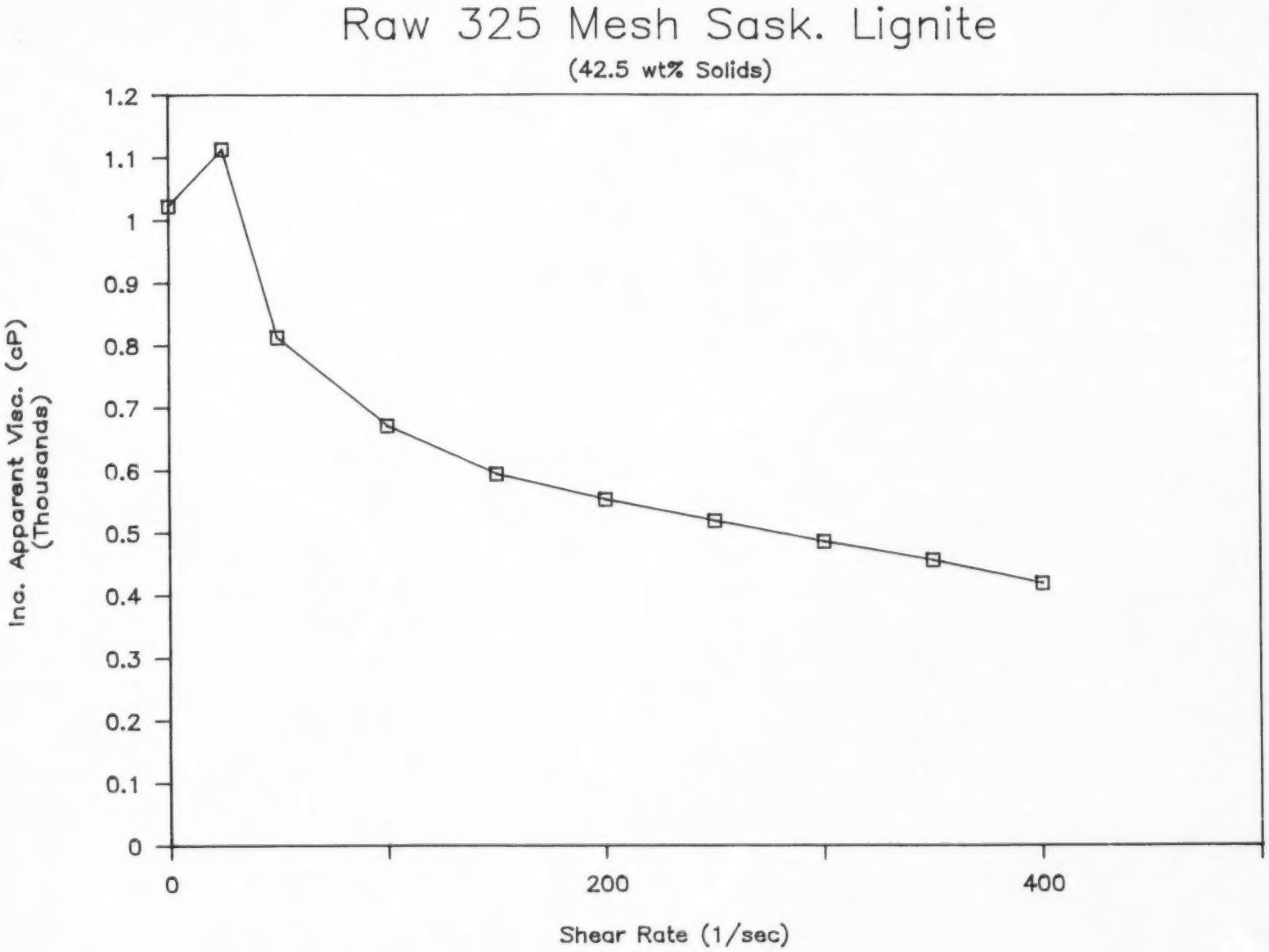

Rheological Performance of Raw and HWD CWF
From 325 Mesh Saskatchewan Lignite
10000
1000
100
10
Apparent Viscosity, cP
38
40
42
44
46
48
50
52
54
56
58
60
Solids Concentration, dry wt%
HWD 80/20 Blend plus additives
HWD 330 C
Raw
HWD 80/20 Blend

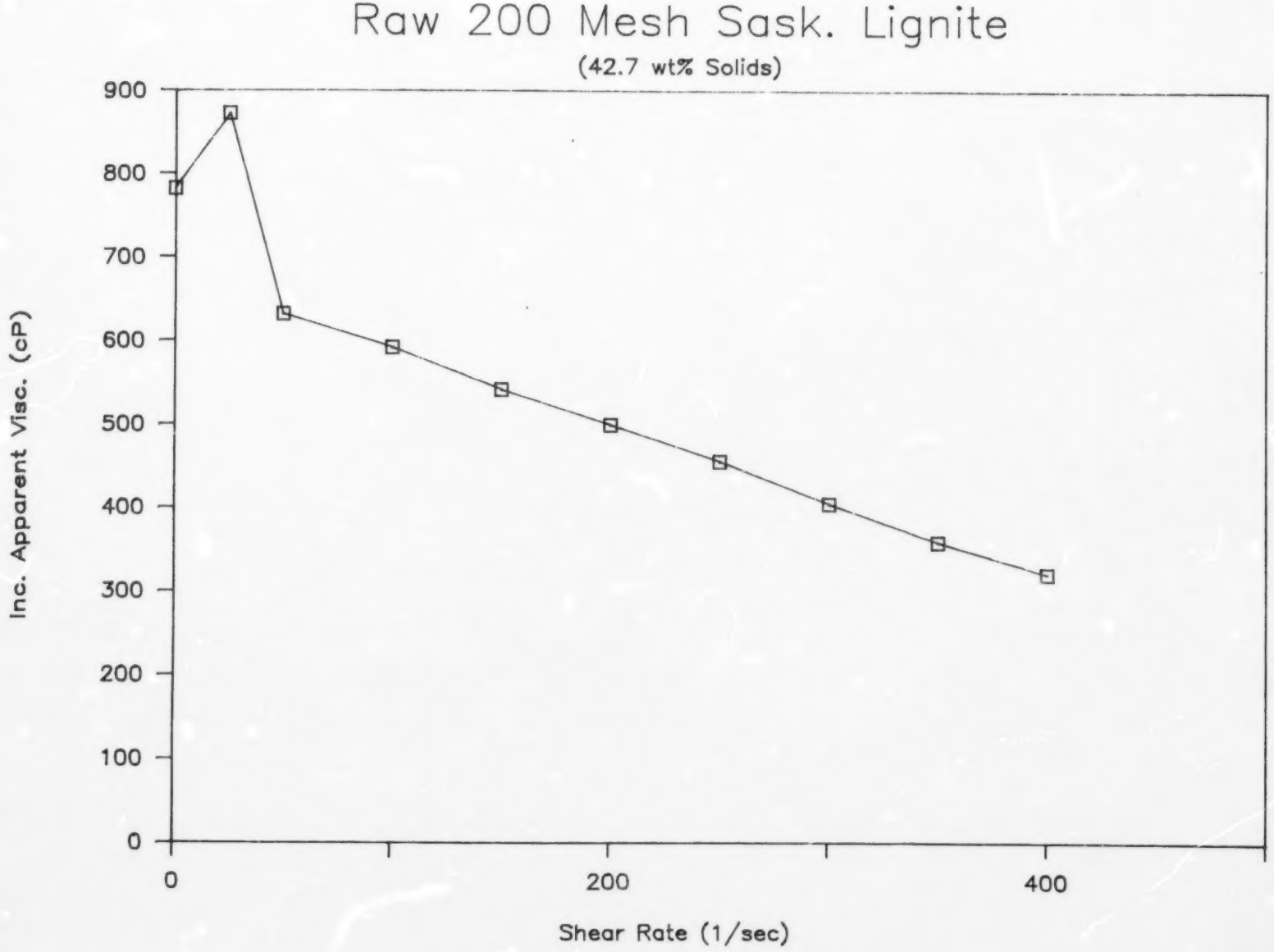

80/20 Blend with 1%ALS and 0.2% X.G.
(54.3% wt% Solids)
Inc. Apparent Visc. (cP)
(Thousands)
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
Shear Rate (1/sec)


Sask. Lignite 80/20 Blend
(53.8 wt% Solids)
Inc. Apparent Visc. (cP)
700
600
500
400
300
200
100
0
0
100
200
300
400
Shear Rate (1/sec)


HWD 325 Mesh Sask. Lignite
(52.8 wt% Solids)
600
500
400
300
200
100
0
Inc. Apparent Visc. (cP)
0
200
400
Shear Rate (1/sec)


HWD 200 Mesh Sask. Lignite
(57.43 wt% Solids)
800
700
600
500
400
300
200
100
0
Inc. Apparent Visc. (cP)
0
200
400
Shear Rate (1/sec)


Raw 325 Mesh Sask. Lignite
(42.5 wt% Solids)
Inc. Apparent Visc. (cP)
(Thousands)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
Shear Rate (1/sec)


Raw 200 Mesh Sask. Lignite
(42.7 wt% Solids)
Inc. Apparent Visc. (cP)
900
800
700
600
500
400
300
200
100
0
0
200
400
Shear Rate (1/sec)